GEOPROCESSING APPLICATION FOR IDENTIFICATION OF POTENTIAL AREAS FOR HYBRID POWER PLANT INSTALLATION

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ABSTRACT

One of the disadvantages of renewable sources in electricity generation is their intermittency. However, this issue can be overcome through hybrid power plants that combine multiple renewable sources, offering benefits such as increased generation scale, infrastructure optimization, efficient resource utilization, and energy matrix diversification. This paper presents a case study conducted in the State of São Paulo, Brazil, with the objective of identifying suitable sites for the establishment of hybrid power plants (solar, wind, biomass, and hydroelectric). The assessment integrates technical, economic, social, and environmental criteria, employing multicriteria analysis techniques, specifically the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC), in conjunction with a Geographic Information System (GIS). Positive outcomes are observed, indicating locations with already installed plants, validating their potential. Thus, the methodology can aid in pre-selecting suitable sites for hybrid power plant development, facilitating effective planning and utilization of the country's energy resources.

Keywords: Analytic hierarchy process; energy planning; geoprocessing system; hybrid power systems; multicriteria analysis.

Introduction

The high availability of renewable resources in the electricity grid contributes to low greenhouse gas emissions, but it increases operational complexity due to the intermittency of generation from sources such as wind and solar, which depend on weather conditions. A solution to intermittency is the combination of complementary sources, that is, sources that have complementary energy availability in time, space, or both [1]. This approach, with proper control and management, can result in a highly efficient and reliable hybrid power plant to meet the electricity demand in different locations [2]. Some of the advantages are resource optimization (using the same substation and transmission line), streamlined environmental permitting (shared environmental impact studies), increased generation scale, optimized transmission line usage, enhanced production stability, and reduced influence of weather fluctuations on generation [3].

In the spatial planning of the renewable energy sector, an efficient decision support tool widely used is a Geographic Information System - GIS. GIS helps save time and money in site planning for resource exploration by considering a database with information on the best locations [4]. However, in Brazil, so far, there have been few studies that address the use of GIS for identifying areas for the installation of hybrid power plants [5].

Therefore, this paper aims to contribute to discussions on hybrid power plants by presenting a case study in the state of São Paulo, which identifies municipalities with the potential for installing hybrid power plants. This work analyzes solar, wind, and biomass sources as well as the proximity to hydraulic generators, unlike similar studies that used GIS and multicriteria method but addressed other sources. For example, Achbab et al. [6] used AHP with fuzzy logic to identify locations for the installation of a wind-solar hybrid system in Dakhla (Morocco), Rekik and Alimi [7] investigated

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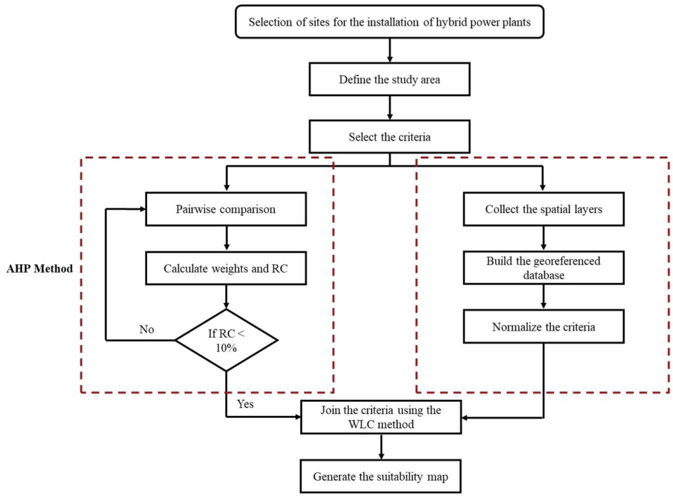
potential sites in Tunisia for the installation of photovoltaic-wind plants, and Yousefi, Motlagh, and Montazeri [8] used the AHP methodology to analyze the wind potential of locations in Iran.

Material and Methods

The methodological framework adopted in this research is illustrated in Figure 1, deriving its foundation from the research contributions of Yousefi, Motlagh, and Montazeri, as well as Davtalab and Alesheikh [9]. In conducting this study, the Geographic Information System software QGIS® (QGIS) and the Excel® software were employed.



Preparation of the geospatial database

Database	Type	Website
Brazilian locations	shapefile	https://www.ibge.gov.br/geociencias/organizacao-do-territorio/estrutura-territorial/27385-localidades.html
Transmission lines	shapefile	https://gisepeprd2.epe.gov.br/WebMapEPE/
Municipalities of São Paulo	shapefile	www.ibge.gov.br/geociencias/todos-os-produtos-geociencias.html
State of São Paulo	shapefile	www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/15774-malhas.html?=&t=acesso-ao-produto
Environmental Conservation Units of Brazil	shapefile	centrodametropole.fflch.usp.br/pt-br/download-de-dados
Existing hydroelectric power plants	shapefile	https://arquivos.epe.gov.br/DEA/SMA/Metadados WebMapEPE/
Existing sugarcane thermal power plant	shapefile	https://gisepeprd2.epe.gov.br/WebMapEPE/
Existing photovoltaic power plant	shapefile	https://gisepeprd2.epe.gov.br/WebMapEPE/
Average global solar radiation	raster	https://globalsolaratlas.info/download/brazil
Wind speed	raster	https://globalwindatlas.info/en/area/Brazil
Sugarcane field	table	metadados.snirh.gov.br/geonetwork/srv/api/records/9e7e1384-6f05-4400-879f-af714e9ab740
Education and wealth index	table	www.iprs.seade.gov.br/#

Figure 1 - Methodology

After defining the study area, an investigation was carried out to identify the most recurrent criteria in studies focused on the selection of suitable locations for photovoltaic, wind, and biomass power plant installations. Additionally, these criteria were categorized into technical, economic, social, and environmental dimensions.

Then, data related to the selected criteria for the defined study area were collected, such as shapefile, raster files, and tables, to establish the georeferenced database in the GIS, as illustrated in Figure 1. All shapefiles were converted to the SIRGAS2000 reference system, and the South America Equidistant Conic projected coordinate system was employed for area and distance calculations. Once imported, this data was processed and standardized to facilitate integration.

Concurrently, the Analytic Hierarchy Process (AHP) method was implemented. This method involves making pairwise comparisons of criteria through a matrix defined by (*n x n*) to determine the relative importance of one criterion compared to another. This comparison is done using a scale ranging from 1 (indicating equal importance) to 9 (indicating extreme importance) as proposed by Saaty in 1980.

After evaluation, the criteria were standardized according to Equation (1), and the weights (w_i¿ were computed using Equation (2). The combination of the criteria was achieved through the WLC method, as described in Equation (3).

$$\overline{Criterion_{ij}} = Criterion_{ij} / \sum_{i=1}^{n} Criterion_{ij} \quad (1)$$

$$w_i = \sum_{i=1}^{n} \overline{Criterion_{ij}} / n \quad (2)$$

$$S=\sum_{i=1}^{n} w_i x_i \quad (3)$$

In Equation 3, S represents the suitability scores of each municipality and x_i the criterion. The higher the score of a municipality, the more suitable it was for the installation of the power plant. However, to consider the weights, it was necessary to verify the consistency of the matrix, which was done by applying Equation (4).

$$RC=\frac{IC}{IR} \qquad IC=\frac{(\lambda m\acute{a}x-n)}{(n-1)} \quad (4)$$

Where λmax represents the maximum eigenvalue of the comparison matrix, and n is the size of the matrix. The IR (Index of Randomness) is a tabulated value associated with the size of the comparison matrix. If the Consistency Ratio (CR) was less than 10%, the matrix was considered consistent.

Results

A. Criteria Selection

According to Malczewski and Rinner [10], the selected criteria should be clear, measurable, and non-redundant to avoid double-counting. Furthermore, the criteria set should be as concise as possible while encompassing all aspects of the decision-making problem. Thus, five criteria were chosen, categorized as technical (horizontal global irradiation, wind speed and biomass area), economic (proximity to transmission lines), social (wealth index and education index), and environmental (percentage of conservation unit). To combine the assessments of the respondents, the Analytic Priority Index approach was employed. This involved aggregating priorities through arithmetic means.

B. Weighting of Criteria

The AHP comparison matrix was created in an Excel spreadsheet and was shared with the academic community of the Federal University of ABC and with groups affiliated with the energy sector through email.The spreadsheet contained a project explanation and instructions for completion.

A total of 10 responses were obtained, but only 8 were used to obtain the final weights because they were consistent according to Saaty's level. Ultimately, the weights were determined as follows: 30.92% for technical criteria, 24.78% for conservation units, 16.15% for the education index, 14.72% for the distance from the transmission line, and 13.43% for the wealth index.

C. Maps of Suitability

Figure 2 shows that the western region of the state of São Paulo presents significant potential for the exploitation of the photovoltaic and wind energy sources. The cities of Álvaro de Carvalho, Guaimbê, and Flórida Paulista stand out as having the greatest potential for both energy sources. In this analysis, wind speed at 100 meters altitude was considered and no speed limit was applied.

On the other hand, Figure 3 highlights the municipalities with potential for the exploitation of photovoltaic energy that are close to hydropower plants. In this analysis, the top three positions are held by the municipality of Igaraçu do Tietê, situated near the Barra Bonita power plant, followed by the municipality of Igarapava, in close proximity to the Igarapava Hydroelectric Plant, and the municipality of Buritizal, located near the Buritis Hydroelectric Plant.

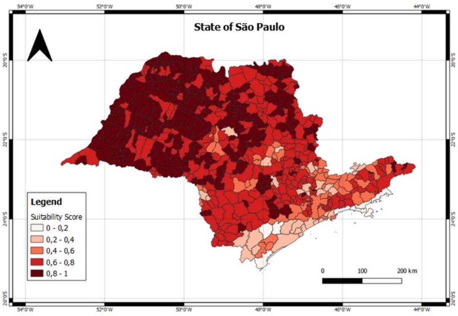


Figure 2 – Suitability map for photovoltaic and wind system

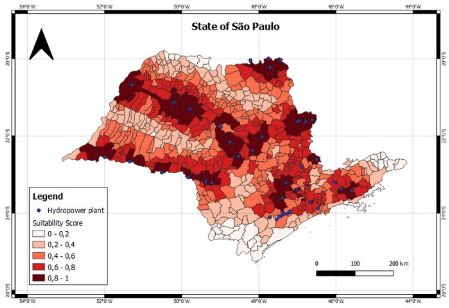


Figure 3 – Suitability map for hydropower and photovoltaic system

The suitability map shown in Figure 4 also considers the wind potential. In this case, the top three positions are held by the municipalities of Igaraçu do Tietê, Itobi, and Canitar.

In the analysis of biomass, the percentage of biomass in each municipality was considered. Given that the interior of the state and the north region have the highest potential, and that the technical criterion held the most significant weight, the adequacy map in Figure 5 highlights these regions.

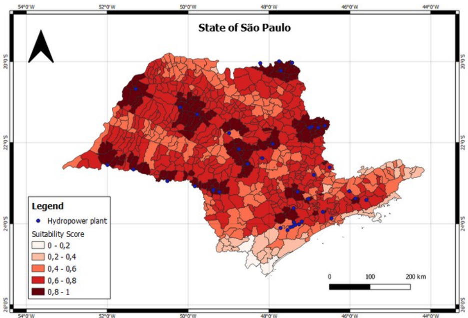


Figure 4 - Suitability map for photovoltaic, wind, and hydropower

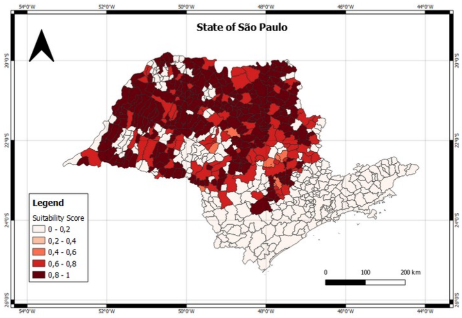


Figure 5 – Suitability map for photovoltaic, wind, and biomass

Finally, Figure 6 displays the suitability map considering all sources. It reveals that the northern region and the interior of the state have the highest potential, with Igaraçu do Tietê, Canitar, and Areiópolis taking the top three positions.

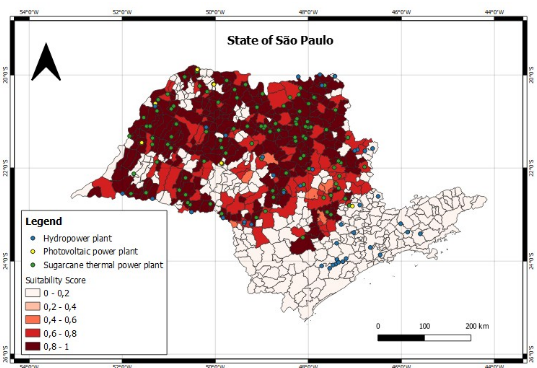


Figure 6 - Suitability map for photovoltaic, wind, biomass, and hydropower

To determine if the method identified locations where power plants already exist, Figure 6 also shows the existing photovoltaic and sugarcane thermal power plants. As can be observed, some of the power plants are situated in regions indicated by the suitability map. In this state, there are no installed wind farms, despite the study indicating areas with potential.

Conclusions

This work presented a case study that employed a multicriteria methodology to identify potential locations for the installation of hybrid power plants, with a focus on solar, wind, biomass, and hydro sources in the state of São Paulo. Technical, economic, environmental, and social criteria were taken into consideration, with weighting carried out through the AHP method and combined through the WLC technique, all processed in QGIS.

One of the main challenges encountered in this work was the acquisition of consistent responses when using the AHP method. It was found that, despite the widespread use of this method in projects involving the identification of potential locations for energy utilization, achieving consistent responses proved to be difficult, even when using the questionnaires in the format of previous surveys. Consequently, the questionnaire underwent various revisions and improvements based on feedback from respondents.

Nevertheless, the study yielded satisfactory results, as it identified power plants in areas already utilizing the study's energy sources. Thus, the methodology can be employed for the pre-selection of potential hybrid power plant sites and is adaptable to different criteria and regions, making it a valuable tool for spatial planning with renewable energy sources.

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